Soil and Water Bioengineering shallow landslide restoration project enhances biodiversity conditions: a study case in Tuscany (Italy)

Emanuele Giachi *, Marco Cabrucci, Agnese Bellabarba, Francesca Decorosi, Andrea Dani, Patrizia Sacchetti, Giacomo Certini, Carlo Viti, Federico Preti * [1]

1. Department of Agriculture, Food, Environment and Forestry (DAGRI), University of Florence, Florence, Italy

HIGHLIGHTS

- The restoration of a landslide using **Soil and Water Bioengineering (SWBE)** techniques promoted **multi-taxonomic biodiversity**.
- The restored site shows **increased soil stability** and advanced **ecological succession**.
- Analyses of herbaceous vegetation, soil microorganisms and pedofauna show differences between the different study sites.
- **Nature-Based Solutions (NBS)** offer both technical and long-term ecological benefits.

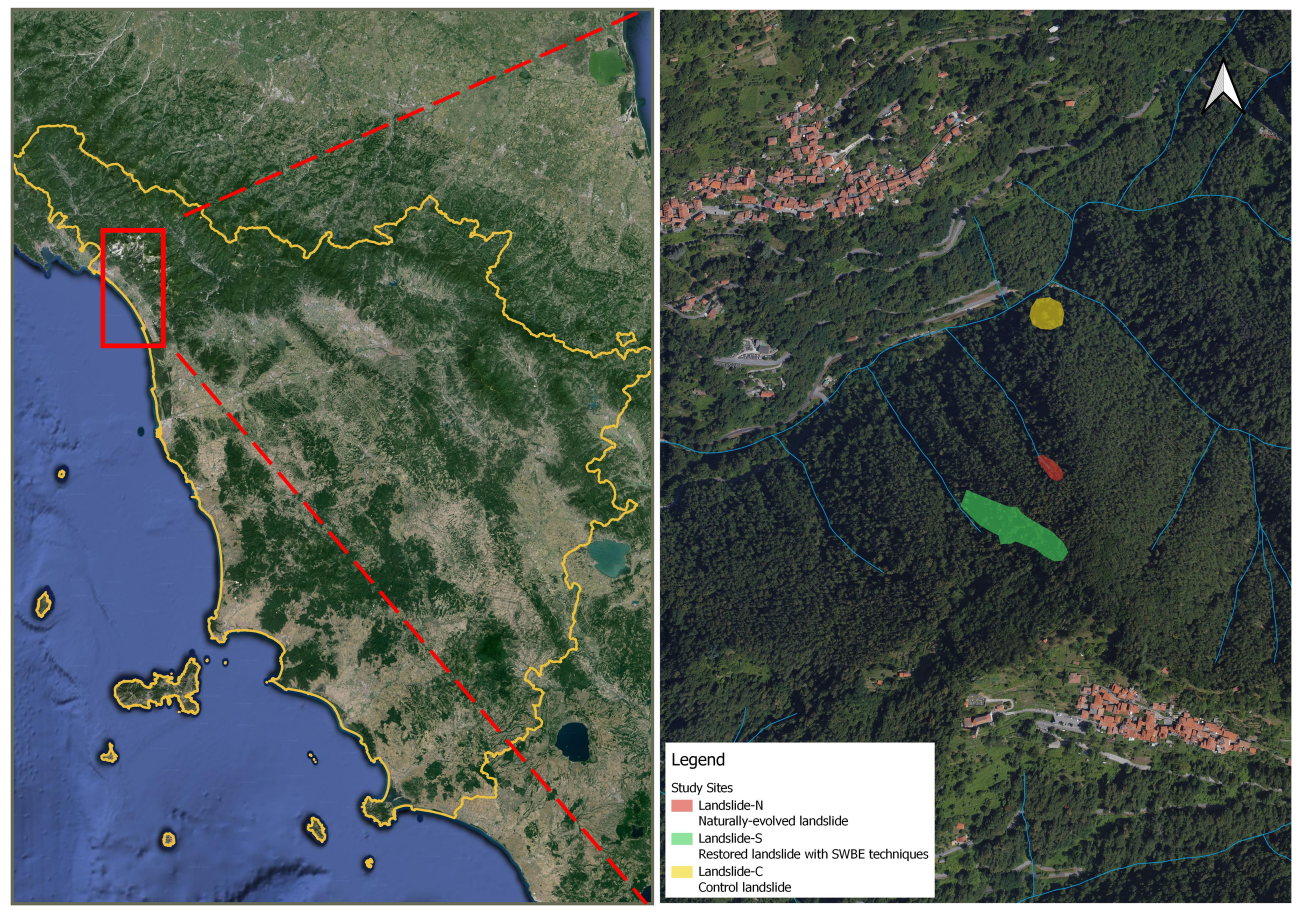
INTRODUCTION

Landslides are complex geomorphological events that not only alter the physical structure of landscapes but also initiate a cascade of ecological processes at both local and regional scales. While **landslides** are often perceived as purely destructive phenomena—with negative impacts on terrestrial and aquatic organisms—they also play a **vital role in ecosystem dynamics**. By exposing new substrates, redistributing soil and organic matter, and modifying hydrological regimes, landslides contribute to nutrient cycling and create opportunities for ecological succession and habitat colonization. Despite their importance, **the ecological processes triggered by landslides** remain underexplored in scientific literature.

In recent years, increasing attention has been given to **ecological restoration strategies** that not only **mitigate geotechnical risks** but also **enhance environmental resilience**. Among these, Nature-Based Solutions (NBS) have emerged as innovative approaches that harness natural processes to restore, protect, and manage disturbed ecosystems. A specific category of NBS, known as Soil and Water Bioengineering (SWBE), combines living plant materials with structural elements such as wood and stones to stabilize slopes, control erosion, and restore vegetation cover. These techniques aim to **simultaneously ensure mechanical stability and promote ecological functionality**, offering a holistic alternative to traditional engineering approaches.

Understanding the long-term ecological outcomes of SWBE interventions is crucial to evaluate their effectiveness beyond technical stabilization. In particular, assessing biodiversity—across multiple taxonomic groups—can provide insights into how restoration efforts influence ecological succession and community assembly following landslide events. **This study addresses this gap by investigating the biodiversity complexity of vegetation, soil microorganisms, and insects in a shallow landslide restored using SWBE methods**, compared to naturally evolved and minimally disturbed control sites in the Apuan Alps (Tuscany, Italy).

CASE STUDY



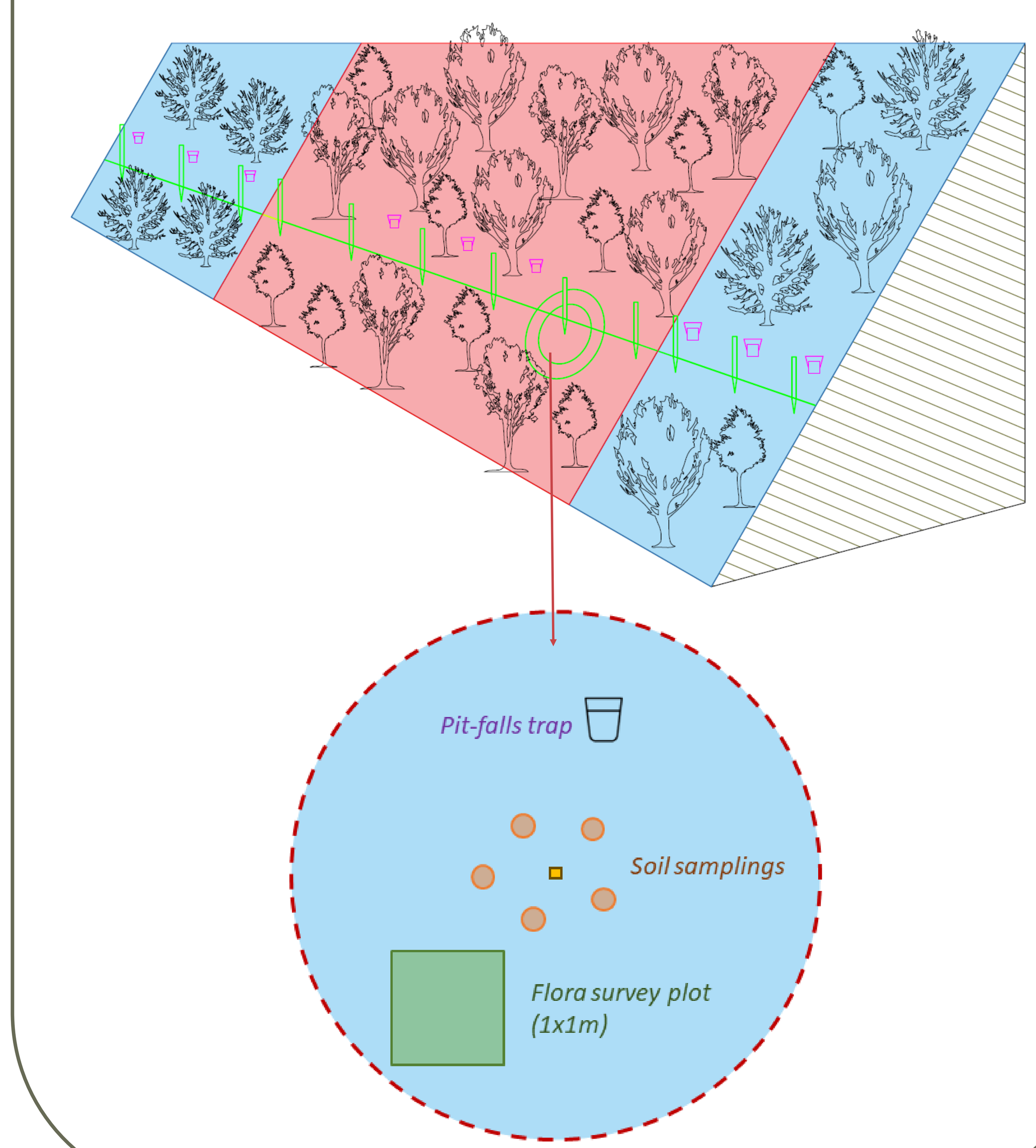
METHODS

MULTI-DISCIPLINARY SAMPLING DESIGN

Vegetation: Trees and shrubs—complete forestry survey; Floristic component—Braun Blanquet method

Pedofauna: pitfalls traps inside and outside landslide different sites.

Soil Micro-organism: soil samples for each sites; Ecoplates analysis for metabolic profile evaluation + Metagenomic analysis (shotgun).

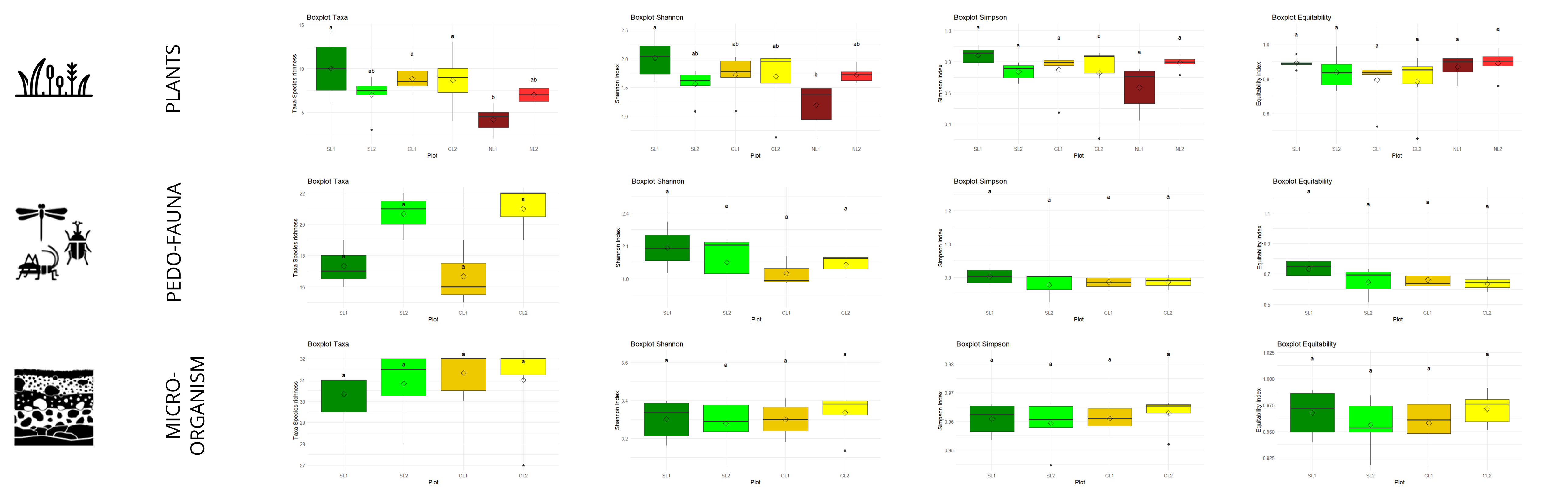


ECOLOGICAL RESTORATION

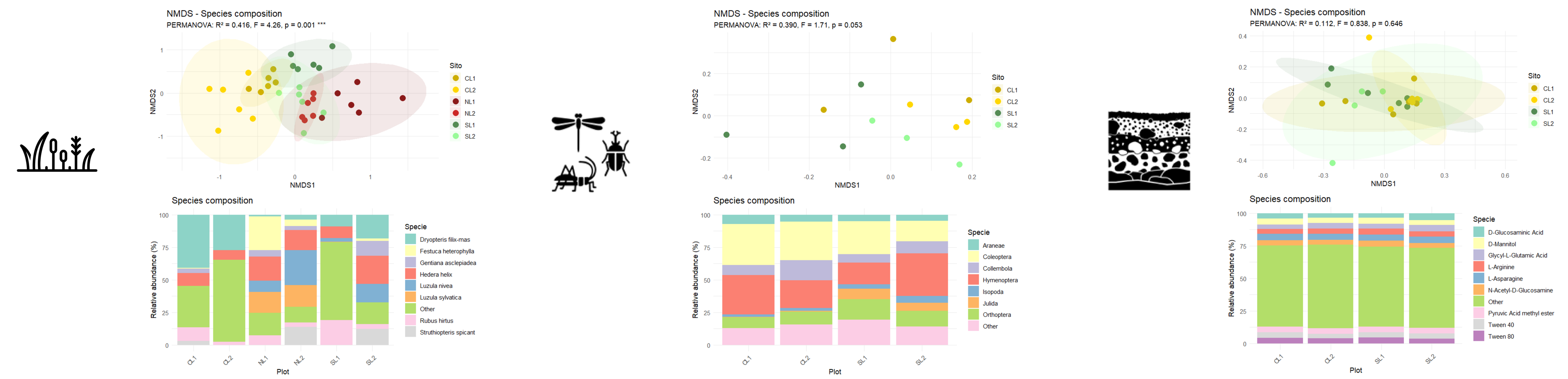
SWBE Technique—live wooden crib wall

RESULTS

ALPHA—DIVERSITY



BETA—DIVERSITY



The analysis of the herbaceous species composition shows significant differences between the plots, PERMANOVA ($R^2 = 0.416$, $F = 4.27$, $p = 0.001$). Beta-dispersion analysis ($F = 1.74$, $p = 0.154$) suggests that these differences are not attributable to variations in multivariate dispersion, but actually reflect variations in floristic composition. These results indicate a well-defined structure of the herbaceous communities between the plots analysed.

PERMANOVA suggests that the plots tend to differ in terms of composition ($R^2 = 0.390$, $F = 1.71$), but this difference is not statistically significant at 5% ($p = 0.053$). However, the p-value close to the threshold may indicate a biologically relevant trend. Beta-dispersion analysis confirmed the homogeneity of the variance between the groups ($F = 0.372$, $p = 0.815$). Overall, the NMDS analysis results suggest that there are trends of differentiation between plots.

PERMANOVA confirms the absence of significant differences in composition between plots ($R^2 = 0.112$, $F = 0.84$, $p = 0.646$). Furthermore, the test for homogeneity of dispersions (beta-dispersion) showed no significant differences between the multivariate variances of the plots ($F = 0.562$, $p = 0.661$), supporting the reliability of the PERMANOVA result. NMDS analysis shows a strong overlap between the sample groups, suggesting a similar composition of soil microbial communities between the different plots.

CONCLUSION AND DISCUSSION

Research findings highlight the **ecological value of Soil and Water Bioengineering** (SWBE) interventions in **post-landslide landscapes**. The restored site not only exhibited **greater slope stability** but also supported a **well-developed ecological succession**, as reflected in both the structural complexity of vegetation and the diversity of soil biota and insect communities. These results indicate that SWBE techniques go beyond their technical role in erosion control and contribute meaningfully to the re-establishment of ecological processes.

Vegetation data revealed higher alpha diversity in the SWBE-restored site, suggesting that stabilized conditions promote both colonization and persistence of a broader range of herbaceous species, also combined trees and heraceous component that contribute also to slope stabilisation (Preti et al., 2025). In parallel, the alpha– and beta-diversity analysis of soil microbial and insect communities show us mainly no difference between the SL and CL sites; diversity indexes trends reveal a better specie community in the restored site.

This study demonstrates the value of using a **multi-taxon approach to assess restoration outcomes**, that could **help us understanding ecosystem recovery dynamics**. The interdisciplinary methodology adopted aligns with current ecological restoration frameworks that emphasize **long-term monitoring** and **ecosystem multifunctionality**.

FURTHER RESEARCH

SWBE techniques represent a promising model for landslide restoration, **where technical stabilization is harmonized with biodiversity enhancement**. **Multi-diversity indices** will be evaluated to highlight the relationships among different taxonomic groups, to better comprehend **ecological processes activated by SWBE restoration**. Their effectiveness depends on both the design and the environmental context, but when properly implemented, they offer a cost-effective, sustainable solution aligned with Nature-Based Solutions principles. Continued monitoring is needed to fully understand the long-term trajectories of biodiversity and ecological function in these systems. Nevertheless, this case study from the Apuan Alps provides evidence for the **integration of ecological criteria** into post-disaster **landscape recovery** and **slope management strategies**.

REFERENCES

Giachi, E.; Giambastiani, Y.; Giannetti, F.; Dani, A.; Preti, F. Root System Evolution Survey in a Multi-Approach Method for SWBE Monitoring: A Case Study in Tuscany (Italy). Sustainability 2024, 16, 4022. https://doi.org/10.3390/su16104022

Preti F., Dani A., Giambastiani Y., Giachi E. Slope stability time evolution of a shallow landslide restored by Soil and Water Bioengineering (SWBE) techniques: A case study in Northwest Tuscany (Italy), Ecological Engineering 2025, 214-107570, ISSN 0925-8574. https://doi.org/10.1016/j.ecoleng.2025.107570

Walker, L. R., and A. B. Shiels. 2012. Landslide ecology. Cambridge University Press, Cambridge, UK.

Università degli Studi Firenze – DAGRI Department of Agriculture, Food, Environment and Forestry

NBFC Land – National Biodiversity Future Center

This study was carried out within the funding from the European Union Next-GenerationEU (National Recovery and Resilience Plan – CN5—National Biodiversity Future Center (NBFC) Spoke 3.

Finanziato dall'Unione europea NextGenerationEU

Ministero dell'Università e della Ricerca

Italiadomani – Piano Nazionale di Ripresa e Resilienza

AIPIN – Associazione Italiana per la Ingegneria Naturalistica – Nature Based Solutions